Simulation of noise emission in the railway traction means

Z. Bazaras
Department of Transport Engineering,
Kaunas University of Technology, Lithuania

Abstract

Noise pollution is an increasing nuisance within the EU member states. In an attempt to pursue measures to combat the problem of noise, the European Commission has in recent years intensified its activities within noise abatement. One such process considered here concerns the harmful consequences of transport usage and the noise generated by transport vehicles, its distribution and its variation in the internal transport vehicle spaces and various noise sources in particular. Engineering, organizational and administrative noise reducing measures are also reviewed along with noise effects considered harmful to human health. Traffic velocities increase as the railway transport rolling-stocks improve technically and become more perfect and sophisticated, the noise generated by them is intensified too and noise limits are exceeded. Several major factors are considered here: the condition of the rail and the wheels, and the type of trains, as well as the question of the specific prediction method used.

Key words: railway transport, internal noise emission, simulation.

1 Introduction

In Europe, noise is a growing problem that is estimated to affect the health and quality of life of at least 25 % of the EU population. While noise pollution comes from several sources, the dominant one is transportation. Around 20 percent of the Union’s population or close on 80 million people suffer from transport noise levels considered to be unacceptable.

The noise pollution problem is being aggravated because passenger and freight traffic will increase dramatically in the years to come. According to projections released by the International Energy Agency in 2002, passenger and
freight transportation in OECD (Organization for Economic Co-operation and Development) Europe will increase, in an approximate twenty-year time period, by 40 and 64%, respectively, with road traffic by far taking the largest share, while rail transport will stagnate. However, as it is the political will of the EC and of some European countries to revitalize railways, we will see traffic increase both on roads and rails and, naturally, in urban areas [1-7].

The need to safeguard the quality of life and health of the population pits efforts for traffic noise abatement against the increasing demand for mobility. To reconcile these presently conflicting needs, the Community has set the target to achieve a reduction of the number of people regularly affected by long-term high levels of noise from an estimated 100 million people in the year 2000 by around 10% in the year 2010 and in the order of 20% by 2020.

Transportation noise is emitted by a large mix of moving sources with permanent changes in temporal and local composition. Perception and effects depend on intensity, composition and temporal distribution. Other influencing factors are environmental factors like weather, topography, and buildings and constructions. The most effective noise reduction is achieved by limiting noise emissions at the source. Due to the long life spans of modern vehicles and infrastructures, technical improvements will penetrate the market only very slowly. Therefore, technical efforts to reduce noise at the source must be supplemented by other measures. These include sound barriers or sound proof windows, noise-dependent traffic management, all of which have immediate, but merely local, results.

2 Analysis noise emission in the railway traction means

In fig. 1 a functional scheme of the existing harmful factors to human health in railway transport is presented.

Legislation norms for noise levels of rolling stocks are defined in the standards. In Lithuania noise of the rolling - stocks are regulated by requisition No. V-520 of minister of health of Lithuania Republic “Hygienic norms HN 33:2003; Acoustic noise. Allowing levels in living and work media. General requirements of measurement methodology”.

3 Methods of simulation of noise emission

Complex evaluation of noise impact to the environment. For the modeling of internal noise in the locomotive we used ANSYS software to create 3D models of internal space of the locomotives body.

Geometry of model consists of four different parts:
1. Internal space of the front control cabin.
2. Internal space of the back control cabin.
3. Communicating tambours to the internal space of the machine section.
4. Internal space of the machine sector, which was divided into 4 areas for convenience forming the finite elements grid.
Figure 1: Scheme of harmful factors to human health.

4 Results of simulation

Noise sources in the rolling-stocks are conditionally grouped into:

I – the noise occurring during the movement of the locomotive. This includes the noise of break-shoes, axle boxes with roller bearings, traction engines, traction reducers and axle-wheel;

II – the noise inside the control cabin. This is the noise caused by the speed meter, the engine driver’s crane, the whistle and the watchfulness signal;

III – the noise inside the machine section. The main source of the noise in the machine section is a power aggregate – diesel, also the noise caused by the ventilators, the reducers of auxiliary aggregates, the main electricity generator, the double machine aggregate, the breaking compressor, the turbo compressor as well as the exhaust system of combustion products.

The source of noise in train depends on speed. The contact of the wheel and track is a dominating source of noise moving at the speed of 80-160 km/h. Measurements of noise of the rail transport facilities are performed according to the order described in the standard documents.

The axle-wheel noise is caused by the interaction between rail irregularities and the bandage rolling on the rail head surface as well as by the sliding of the wheel along the rail in longitudinal and cross directions. The vibrations of the bandage and the wheel center can cause the wideband spectrum noise level up to
120 dB. The axle-wheel noise may be drowned by the gear noise when the movement speeds are low and loads are big.

The rolling noise largely depends on the movement speed of the rolling-stock. Normally, the sound pressure rate increases by 9 dB with the double increase of speed [9]. The wheel-caused noise may be different with regard to the type of the rolling-stock. The irregularities of interacting surfaces agitate the vibrations of the wheel and the rail under the influence of the masses inherent in the movement. Vibrations of different amplitudes are agitated in them depending on the properties and geometrical forms of the materials of the rail and the wheel. The motion of these bodies’ surfaces causes the vibrations of the air particles, thus inducing the ambient air noise.

The noise in railway transport facilities is measured by the procedure established by the following standard documents:


The general diagram can be conveniently represented by signal graphs. The joints in the graph represent variable energy flows (sources), and the radii are understood as the sound energy transmitting channels defined by the reduction indices of sound energy intensity.

Referring to the signal graph the sound power flow $J_{is}$ in the analyzed direction of the sound field of the rolling-stock is written as follows:

$$J_{is} = W_iC_1 + W_2C_2 + \ldots + W_iC_i = \sum_i W_iC_i$$

and the intensity rate $L_{is}$ by its numerical value equal to the sound pressure rate expressed in dB is written as follows:

$$L_{is} = 10\log_{10}J_{is}/J_0 = 10\log_{10}\sum_i W_iC_i/J_0 \leq [L_{is}]$$

here $W_1, W_2, \ldots, W_i$ is sound capacity of the noise sources; $C_1, C_2, \ldots, C_i$ are indices involving intensity reduction with the increase of distance from noise sources; $J_0$ is the limit value of sound intensity, $J_0 = 10^{-12}$ W/m$^2$ [8]; $[L_{is}]$ is the rate of permissible external noise.

Two ways for determining sound energy in the rolling-stock cabin are used: from each source via all elements of the cabin or form all sources via each element of the cabin. For the first version of calculation the sound energy in the cabin is expressed as follows:

$$W_{Ki} = W_i(K_1^1 + K_2^2 + \ldots + K_i^i + K_m^m) = W_i\sum_i K_i^i$$

for the second version of calculation:

$$W_{km} = (W_1K_m^1 + W_2K_m^2 + \ldots + W_iK_m^i)\tau_m = \tau_m\sum_i W_iK_i^i$$
where $K_1^\prime, K_2^\prime, \ldots, K_i^\prime$ and $K_1^*, K_2^*, \ldots, K_i^*$ are indices evaluating the transfer of sound energy to the surfaces of relevant partitions; $\tau_1^\prime, \tau_2^\prime, \ldots, \tau_m^\prime$ and $\tau_1^*, \tau_2^*, \ldots, \tau_m^*$ are indices evaluating the transfer of sound energy through relevant partitions.

The number of signal graphs in the diagram being calculated is defined by the number of noise sources being evaluated, as well as by the number of elements homogeneous according to sound permeability in all surfaces of the cabin. The calculations are carried out according to the corrected and octave sound capacity values by evaluating relevant values of transfer indices $\tau$ – sound permeability partitions. Evaluating the dependence (eqn. 4) the total sound intensity in the cabin will be:

$$J_k = \sum_W W_k \alpha$$

(5)

here $\sum W_k$ is the total sound energy of the cabin, calculated by the formula:

$$\sum W_k = \sum_i W_{ki} = \sum_i W_{km}$$

(6)

The noise rate (sound pressure ratio) in the cabin of the rolling-stock is calculated by the formula:

$$L_K = 10 \lg \left[ \frac{\sum W_k}{(\alpha S_w J_0)} \right] \leq [L_K]$$

(7)

here, $[L_K]$ is the allowed noise rate in the cabin.

Transmission indices $C_i$ evaluating the reduction of sound intensity with the increase of the distance from the point source are determined by the relationship:

$$C_i = \frac{1}{\Omega_{ri}}$$

(8)

here, $r_i$ is the distance of the $i$-th noise source to the field point of the cabin sound of the rolling-stock in question; $\Omega = 4\pi$ – for spherical sound radiation, $\Omega = 2\pi$ – for semi-spherical sound radiation (semi-spherical sound radiation will be for $H \leq r_i / 3$, here $H$ is the agreed point source height above the road surface).

The transmission indices $K_i$ in the eqns (9) and (10) are calculated by the formula:

$$K_i = \frac{S_i}{\Omega_{ri}^2}$$

(9)

here, $S_i$ is the surface area of the partition.

The index of sound energy transmission through the partitions (sound permeability coefficients) is calculated:

$$\tau_i = 10^{-0.1 R_i}$$

(10)

here, $R_i$ is the sound isolation of the partition.

The presented acoustic calculation model of rolling-stock cabin allows the evaluation of structural solutions and, in case of emergency, taking extra measures in the process of rolling-stock design.
In the ANSYS/Multiphysic ambience the problems of acoustics are resolved on the basis of the analysis of harmonic response, by providing the harmonic pressure agitation (sinus type) at some points of fluid structure and obtaining the pressure distribution in the fluid. By changing the agitation frequency, variable sound distribution in the interval of different frequencies is obtained [7-9].

The stages of harmonic acoustic analysis are as follows:

1. Formation of the model.
2. Indication of limit conditions and acoustic loads as well as the solution of the finite elements model.
3. Review of results.

### 4.1 Formation of model geometry

The internal space model of the locomotive body is formed of individual areas: internal space of the front control cabin, internal space of the back control cabin, communicating tambours to the internal spaces and of the machine sections, internal space of the machine section [7].

### 4.2 Limit conditions of the model and loads

In constructing the calculation diagram for the front locomotive, the flat construction of finite elements is used. All the construction was described by 3D finite elements FLUID30 designed for a specified acoustic analysis. These acoustic elements have the following degrees of freedom: displacements UX, UY and pressure PRES. For acoustic finite elements FLUID30 the following characteristics of the material are to be specified: air density DENS, sound velocity in the air SONC and damping index MU. Also, the real constant is to be indicated, i.e. the sound pressure value taken as a hearing limit – $p_0 = 2 \cdot 10^{-5}$ N/m² [8].

On formation of the grid of finite elements and tightening of linear displacements of the body walls, ceilings and floor junctions as well as in the interior body space the interaction surfaces of the fluid and a solid structure are indicated. They are the floor surfaces of the locomotive (loaded by the outside noise caused by the rolling of axle-wheels), as well as the agreed surfaces of diesel and ventilator. On the surfaces of the model the interaction between the vibrating structures and fluid particles occurs. Also, the acoustic load, i.e. the harmoniously varying pressure corresponding to the sound pressure levels existing on these surfaces is also indicated on these surfaces [7-8].

For the modeling of internal noise in the locomotive we used ANSYS software to create 3D model of internal space of the locomotives body.

Geometry of model consists of four different parts: internal space of the front control cabin; internal space of the back control cabin; communicating tambours to the internal space of the machine section; internal space of the machine sector.
Figure 2: Comparison of noise levels in the cabins of TEP60 locomotive using 2D and 3D models with existing legislation norms N80 and N85.

Figure 3: Comparison of noise levels in the cabins of M62 locomotive using 2D and 3D models with existing legislation norms N80 and N85.

5 The solution of the model formed

Depending on the sound wave frequency, insulation materials as well as the interior elements the damping characteristics vary. Therefore, the calculations are performed by varying the agitation frequency in terms of internal geometric frequencies of octave bands and by accordingly changing the damping
coefficients of the parameters defining the sound energy damping surfaces of the model. Noise levels in the control cabins of the locomotives TEP60 and M62 aren’t equal driving at the maximal permissible speed 120 km/h due to the difference in power (TEP60 - \( N_e = 2237 \) kW, M62 - \( N_e = 1421 \) kW) [8]. Internal noise in the cabins of these locomotives is presented in figs. 2 and 3.

In figs. 2 and 3 there are shown changes of noise levels \( L \) in the locomotive cabin of the locomotives TEP60 and M62, when noise of the riding wheels increases. Noise in the locomotive cabin increases due to the increasing velocity of the train.

![Figure 4: Noise variation in 3D model with minimal sound-absorbent characteristic.](image)

The calculations are carried out when changing the agitation frequency and damping parameters. One of the essential indices of human comfort is the level of noise in his working and domestic environment. The permissible noise levels in thermal trucks according to OSShD recommendations are the following:

- long-term noise – \( N_{80} = 80 \) dB,
- interrupted noise – \( N_{85} = 85 \) dB.

### 5.1 Sound insulation dependence on damping index

Sound insulation dependence on damping index is shown in figs. 4 and 5. These figures illustrate the way to dramatically the value of noise pressure changes in front of the wall of the engine driver’s cabin and behind it when the sound absorption is the biggest. And vice versa, for the minimal absorption of the...
sound the noise level in the front cabin of the passenger locomotive TEP60 is over 115 dB at the driver’s shoulder level.

In conclusion it can be stated that working conditions of the railway workers working in propulsion rolling - stocks are unacceptable. The statistical data show that almost as many as half of all transport workers suffer from different health problems caused by harmful effect of noise [1].

Figure 5: Noise variation in 3D model with maximum sound-absorbent characteristic.

For the minimal absorption of the sound the noise level in the front cabin of the passenger locomotive TEP60 is over 115 dB at the driver’s shoulder.

6 Conclusions

1. Noise in high frequency ranges of the exploited rolling stocks in Lithuania increases up to 25 dB legislation norms. Main sources of noise pollution have mechanical character – main and additional force aggregates, road-wheel interaction, braking equipment, noise isolation equipment.

2. The highest noise level difference before and behind the control cabin walls reach 25 dB in locomotive TEP60. Highest noise level in the control cabin of the passenger locomotive TEP60 is 106 dB, the locomotive M62 – 106 dB and in the machine section of the locomotive TEP60 –120 dB, the locomotive M60 – 125 dB in the 31.5 – 250 Hz frequencies range of sound.

3. Comparing 2D and 3D noise emission simulation results, the results from 3D show a 20 % higher precision factor.
References